GLADE : an opportunity for LAr exploitation of the NuMI beam

(Global Liquid Argon Detector Experiment)

5kt LAr detector at Ash River in NuMI beam

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- Gina Rameika
- Leigh Whitehead
- Pawel Guzowski
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- Brian Rebel
- Alfons Weber
- Ryan Nichol

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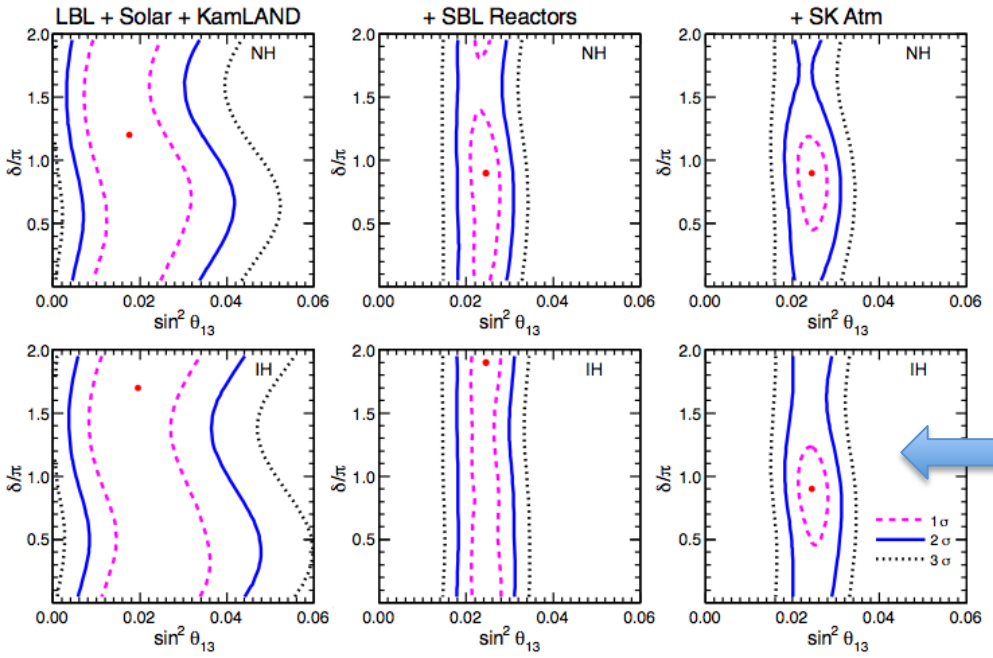
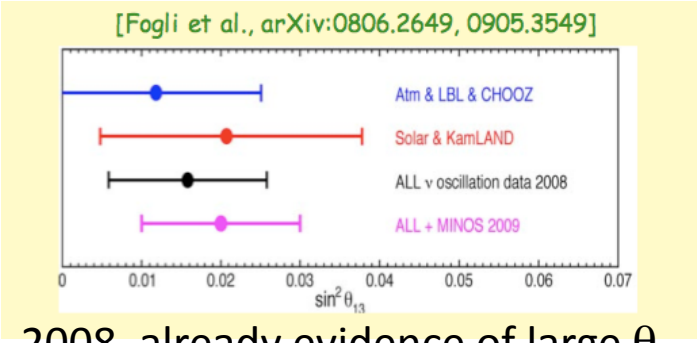
FNAL PAC Aspen June 2012

Introduction

- Why might this be a good idea?
  - Physics
  - Engineering
  - Sociology
- The field is rapidly changing: each new neutrino (slight exaggeration) is providing information to the global picture





2008, already evidence of large θ_{13}

- Pre-Kyoto results (Fogli et al. (arXiv:1205.5254v1 [hep-ph] 23 May 2012)

Introduction

- Why might this be a good idea?
  - Physics
  - Engineering
  - Sociology
- The field is rapidly changing: each new neutrino (I exaggerate) is providing information to the global picture
- The focus is now on the mass hierarchy and CP violation but the sharks are circling
  - Daya Bay Long Baseline : 3-5 years (3σ)
  - PINGU : 3-5 years? (3-11 σ)
  - NOVA : perfectly placed to make a fundamental contribution and could be lucky (2-3σ for one quadrant of δ_{CP})
- GLADE would be equivalent to doubling the NuMI beam power
  - NuMI tap is about to be turned on, we need more buckets!!
  - GLADE short term timescale will allow FNAL to be part of discovery

Introduction

- Why might this be a good idea?
  - Physics
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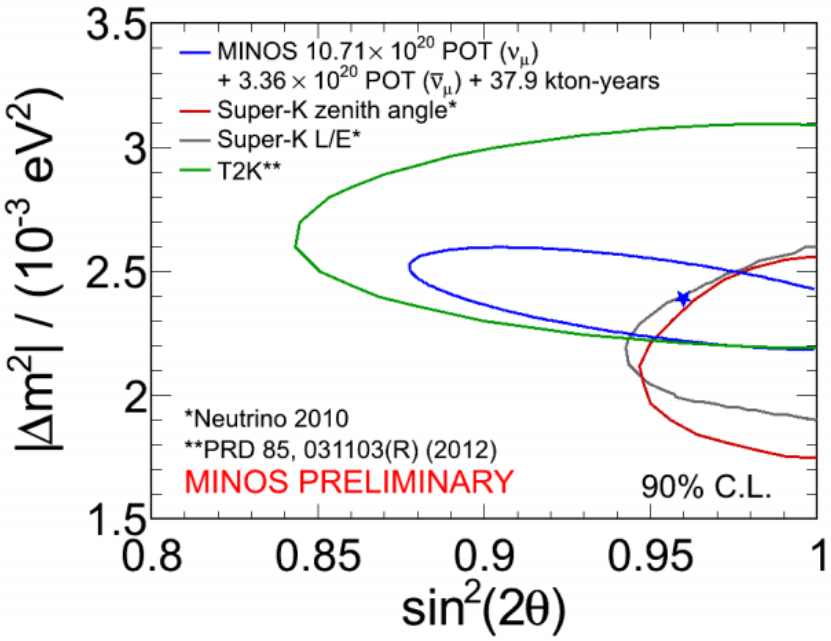
- Large LAr detectors proposed for the future in Europe, US, Japan
  - So far, largest built is ICARUS (600T)
- Engineering for a 10kT object is 20x 600T
- 5kT is large enough to do physics & 10x over ICARUS
  - ICARUS built 600T with a similar increase over the previously built example
- Much of the engineering could be shared with LBNE to enable a fast startup for them if they want/need it
- Reco algorithms will be written and demonstrated for LBNE

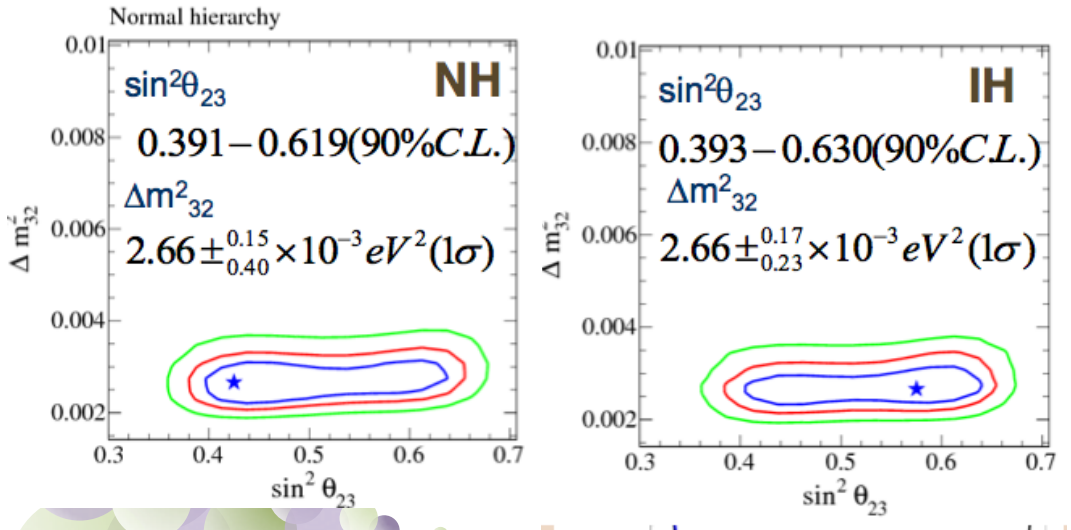
Introduction

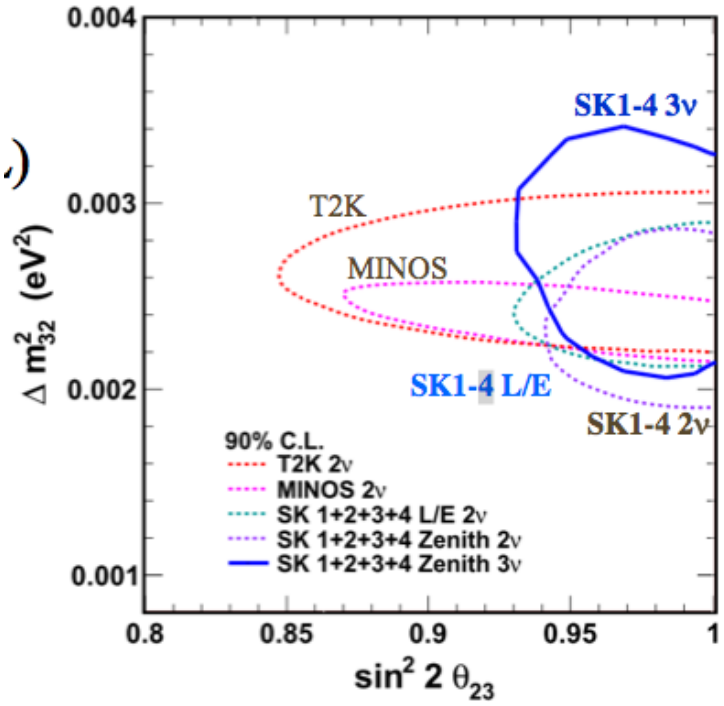
- Why might this be a good idea?
  - Physics
  - Engineering
  - Sociology
- Time scale is perfect for people who need to build and exploit something in the next 4-6 years
  - Construction staff at Ash River will be finishing NOνA
  - Tenure track scientists cannot wait for LBNE and we WILL lose them to the competition
  - FNAL has a great resource (NuMI) which is about to be critically under-utilized and that is not good for FNAL nor for neutrino science!
- Aside: Large scintillator and H20 is being dreamed of: FNAL should put detectors everywhere to soak up that beam!!
- Who on the steering group will be active in another 10-15 years time? I will be retired already!

State of the art from Neutrino 2012

- MINOS and Super-K with $\sin^2 2\theta_{23} < 1.0$







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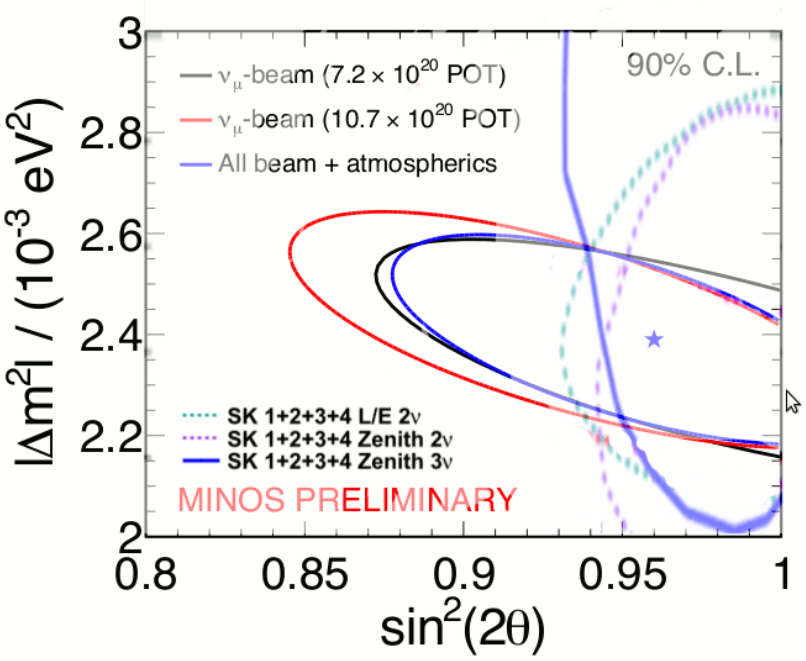

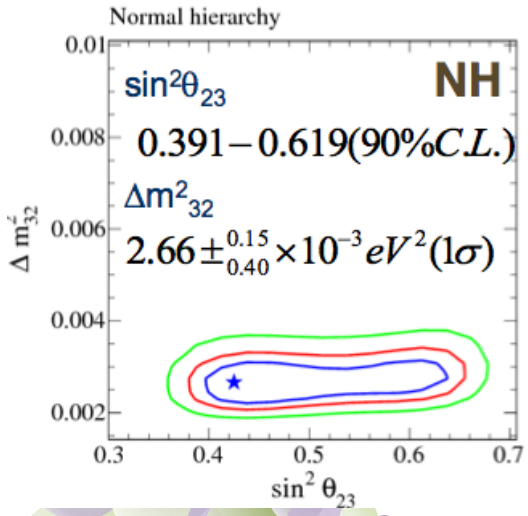

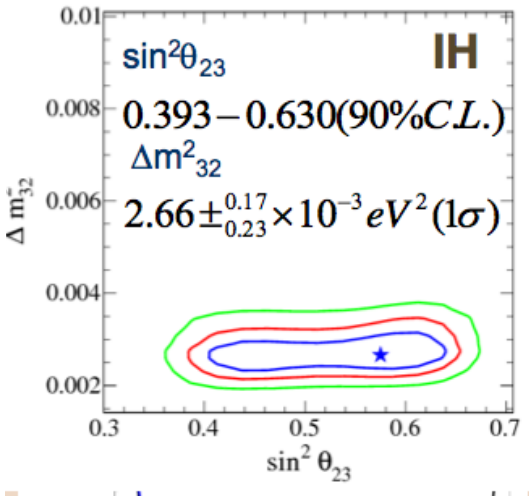

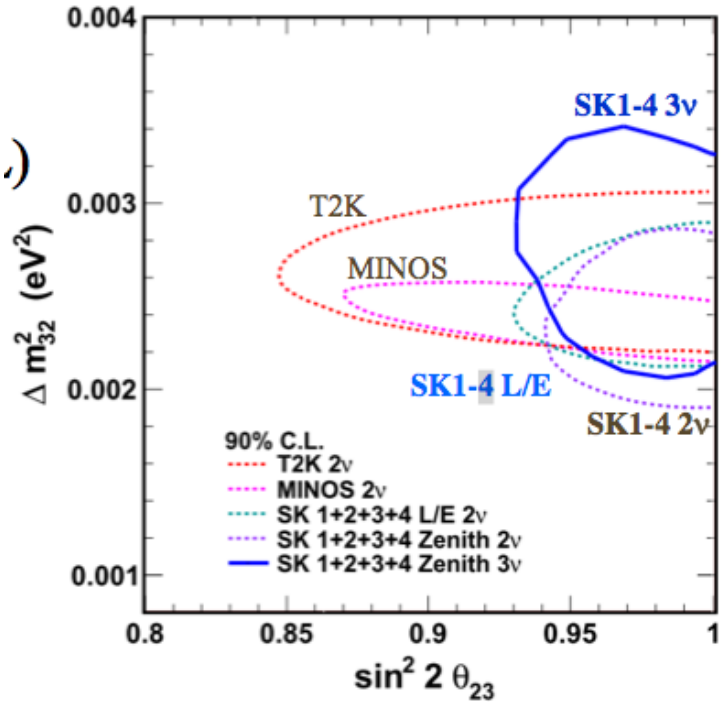

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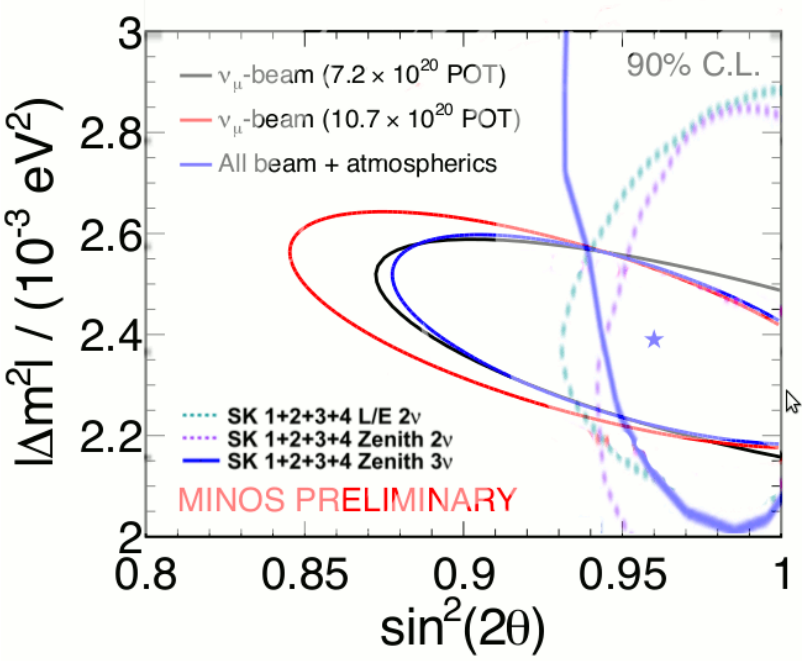
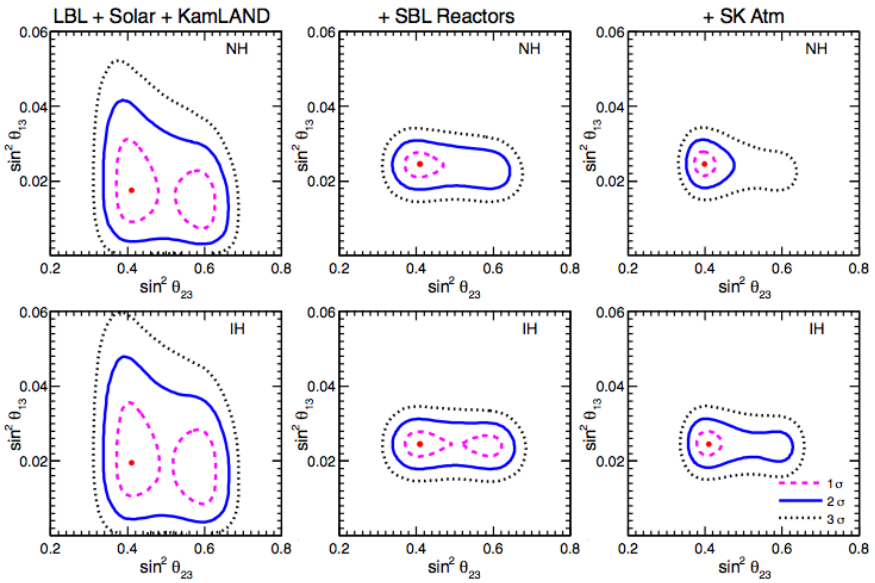
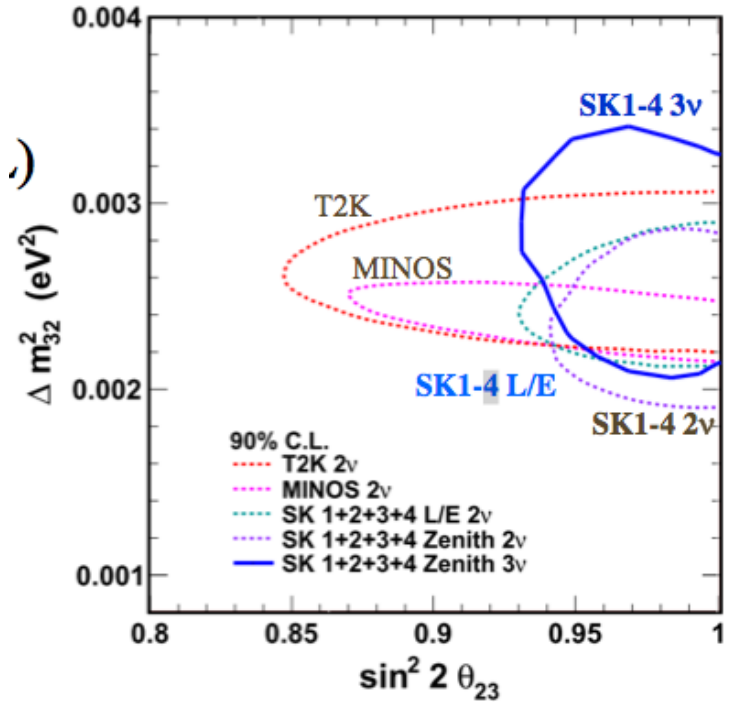
- Fogli already prefers $\sin^2\theta_{23}<0.5$ pre-Kyoto







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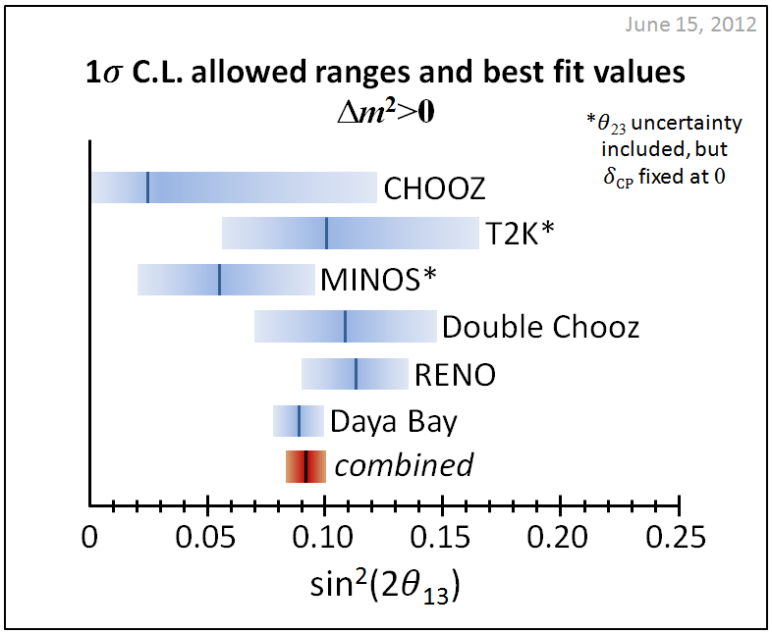

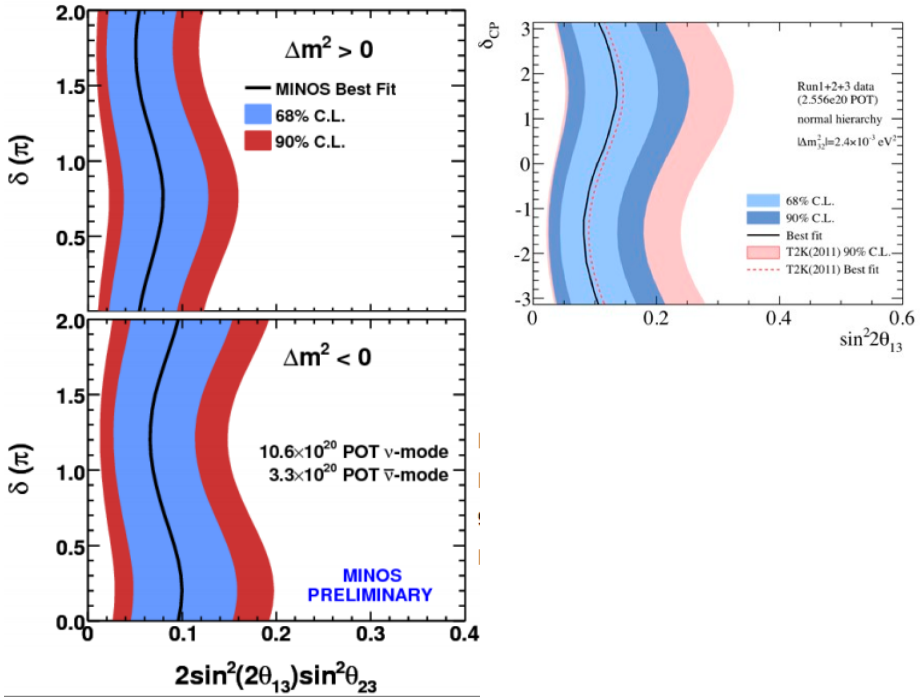

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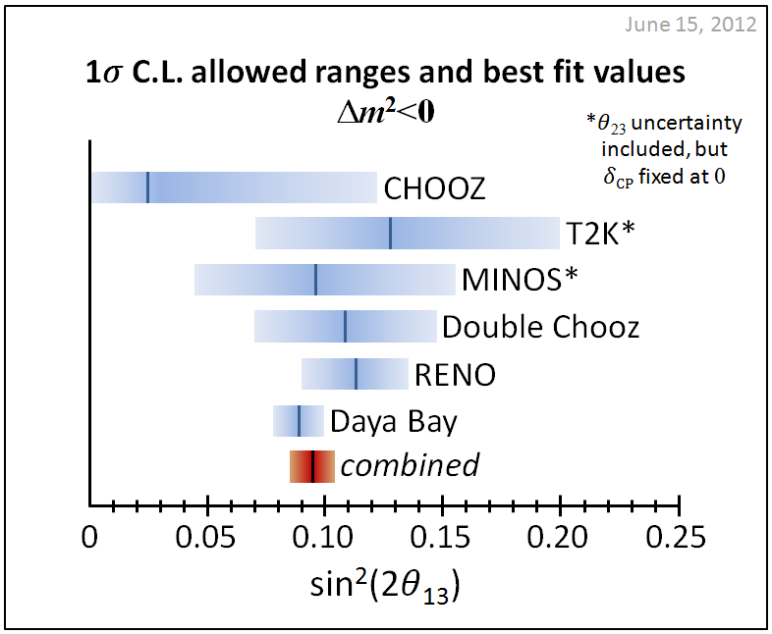

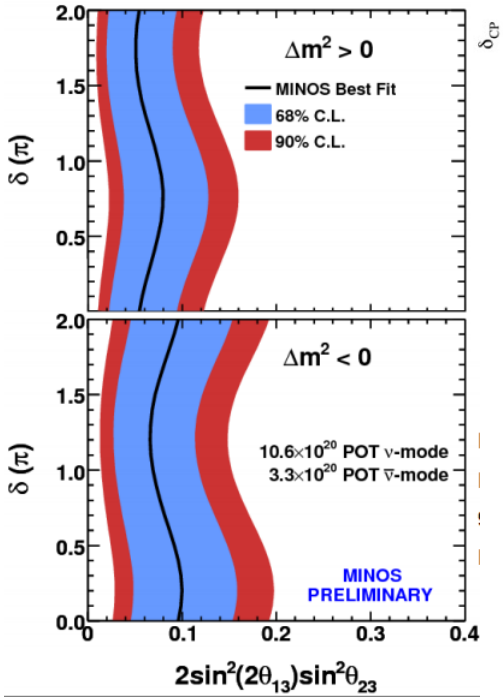

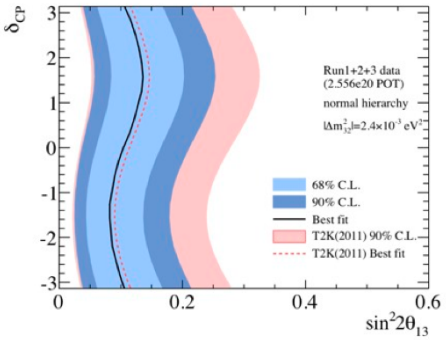

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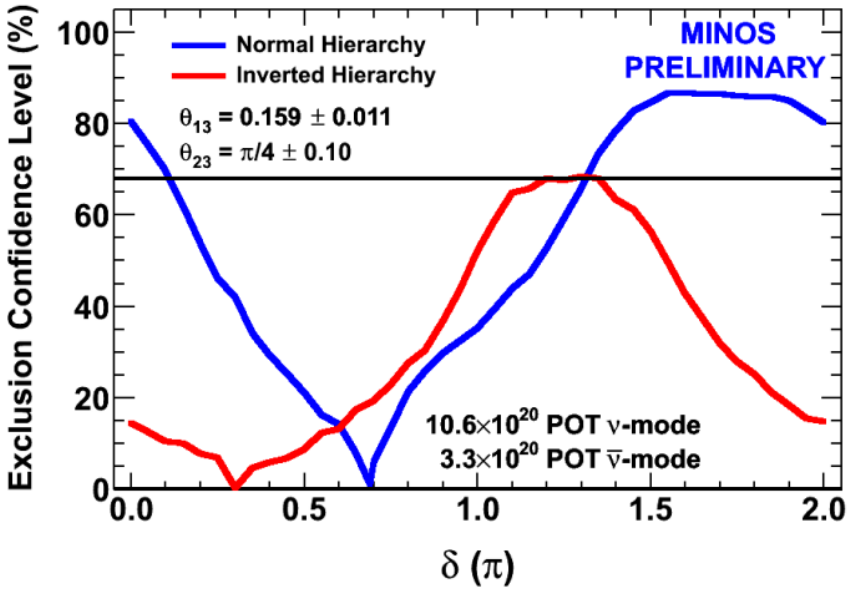

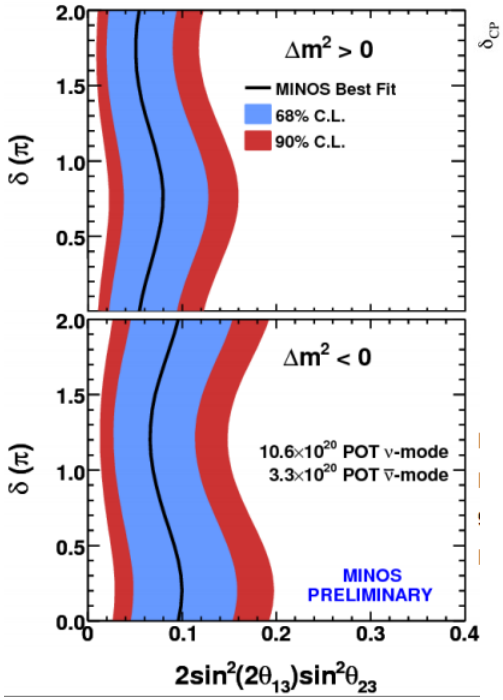

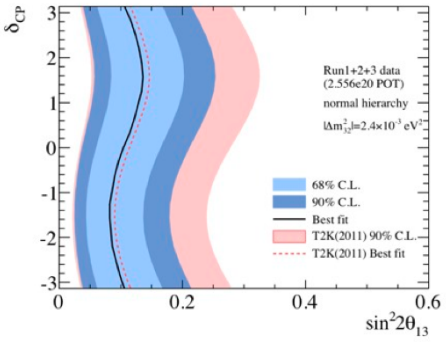

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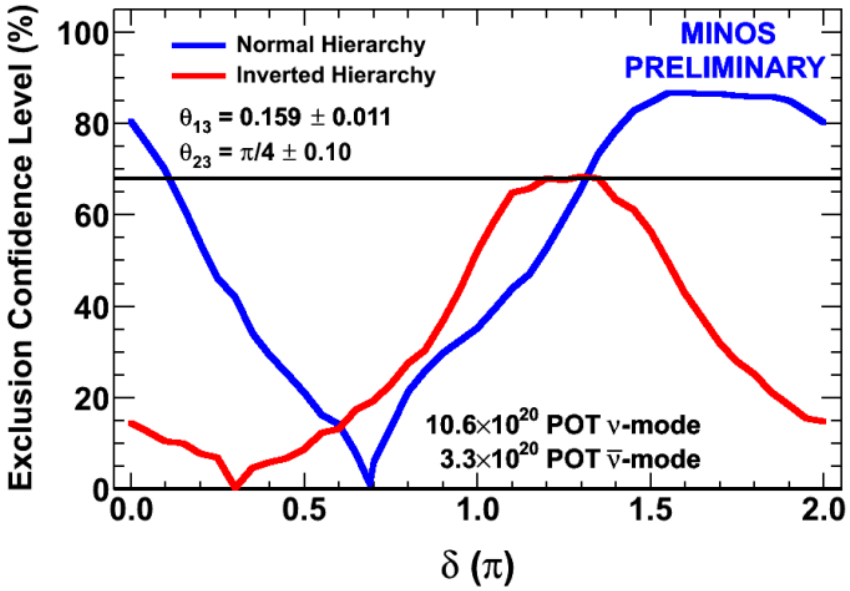
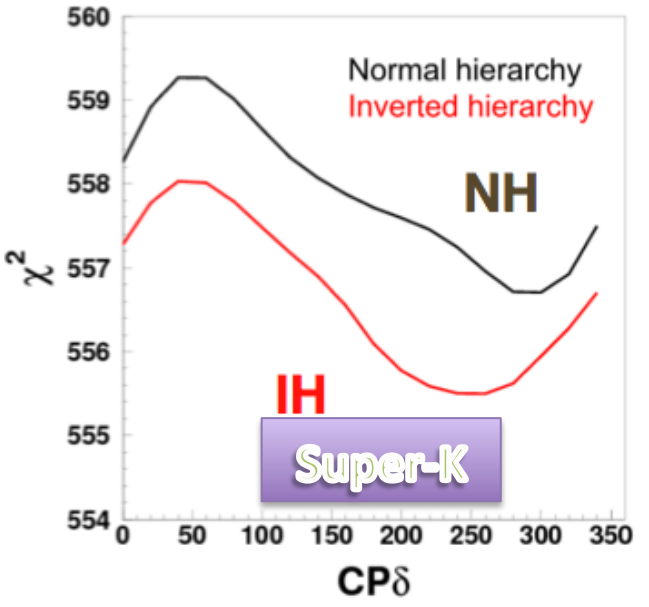
- Theoretical predictions from Yanakida:
  - Inverted Hierarchy
  - $|\delta_{CP}|=\pi/2$
  - $\langle m_\nu \rangle$ =43meV





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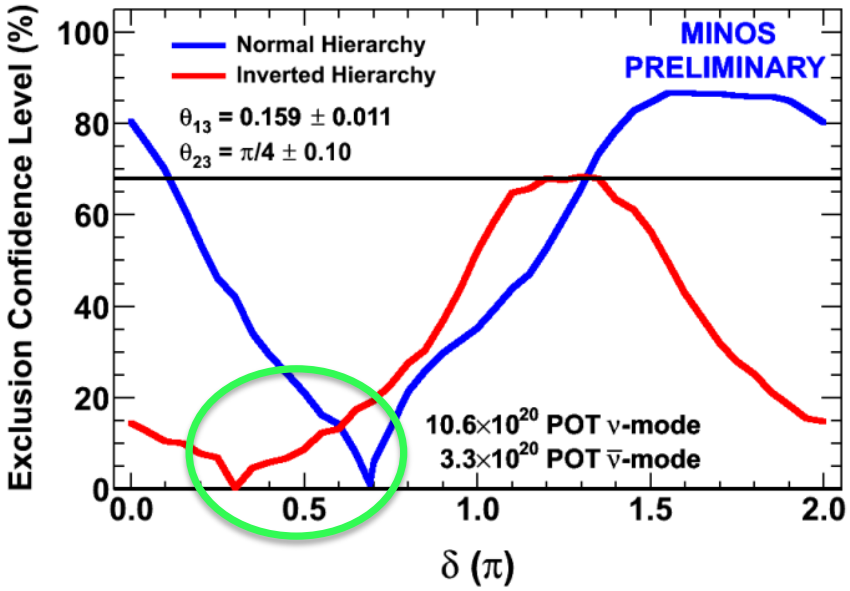

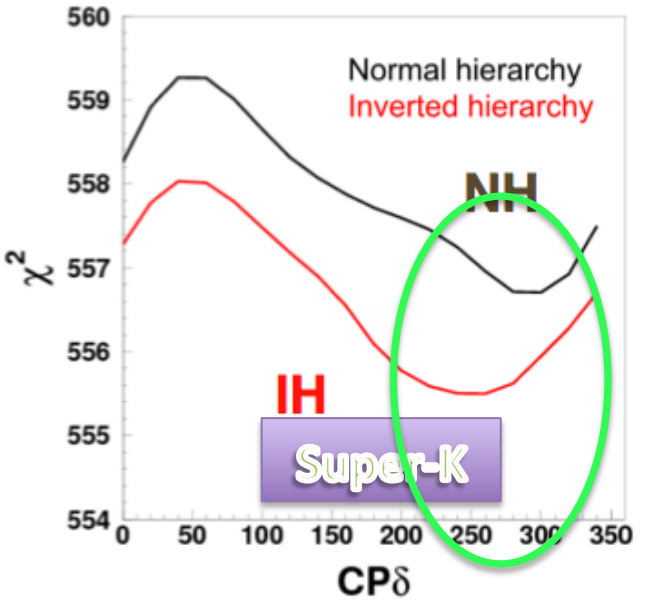

Moving on to the future!

- While Fogli is working out how all this new information is still consistent with the old information……

- How do we directly measure
  - Mass Hierarchy
  - δ_{CP}
- With long baseline accelerator experiments?

How does it work? ν_e appearance!

- At L/E~500 km/GeV, dominant oscillation mode is $\nu_\mu \rightarrow \nu_\tau$
- ~5% of the missing ν_μ should change into ν_e

$$P\left(\nu_\mu \rightarrow \nu_e\right) = \left| \sqrt{P_{atm}}\, e^{-i\left(\frac{\Delta m^2_{32} L}{4E} + \delta_{cp}\right)} + \sqrt{P_{sol}} \right|^2$$

$$P_{atm} = \sin^2\theta_{23} \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E}\right) \qquad P_{sol} \approx \cos^2\theta_{23} \sin^2 2\theta_{12} \sin^2\left(\frac{\Delta m^2_{21} L}{4E}\right)$$

"Atmospheric" Term
Depends on Δm^2
And θ_{13}

"Solar" Term
<1% for current accelerator experiments

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$$2\sqrt{P_{atm}}\sqrt{P_{sol}} \cos\left(\frac{\Delta m^2_{32} L}{4E}\right) \cos\delta_{CP} \mp 2\sqrt{P_{atm}}\sqrt{P_{sol}} \sin\left(\frac{\Delta m^2_{32} L}{4E}\right) \sin\delta_{CP}$$

Interference Term
- for neutrinos
+ for antineutrinos

if $\delta_{CP} \neq 0$,

$$P\left(\nu_\mu \rightarrow \nu_e\right) \neq P\left(\bar{\nu}_\mu \rightarrow \bar{\nu}_e\right)$$

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$$P_{atm} = \sin^2\theta_{23} \sin^2 2\theta_{13} \sin^2\left(\frac{\Delta m^2_{31} L}{4E} - aL\right) \left| \frac{\frac{\Delta m^2_{31} L}{4E}}{\left(\frac{\Delta m^2_{31} L}{4E} - aL\right)} \right|^2 \qquad P_{sol} \approx \cos^2\theta_{23} \sin^2 2\theta_{12} \sin^2(aL) \left| \frac{\frac{\Delta m^2_{21} L}{4E}}{aL} \right|^2$$

$$a = \pm \frac{G_F N_e}{\sqrt{2}} \approx (4000 \text{ km})^{-1}$$

In matter, additional term in Hamiltonian from ν_e + e CC scattering modifies oscillation probability, ~30% effect at NOνA baseline

How does it work? ν_e appearance!

- At L/E~500 km/GeV, dominant oscillation mode is $\nu_\mu \rightarrow \nu_\tau$
- A few percent of the missing ν_μ should change into ν_e

$$P\left(\nu_\mu \rightarrow \nu_e\right) = \left| \sqrt{P_{atm}}\, e^{-i\left(\frac{\Delta m^2_{32} L}{4E} + \delta_{cp}\right)} + \sqrt{P_{sol}} \right|^2$$

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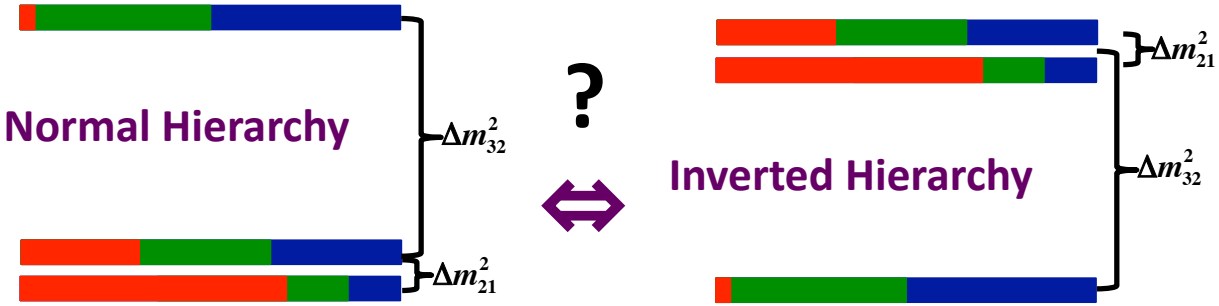
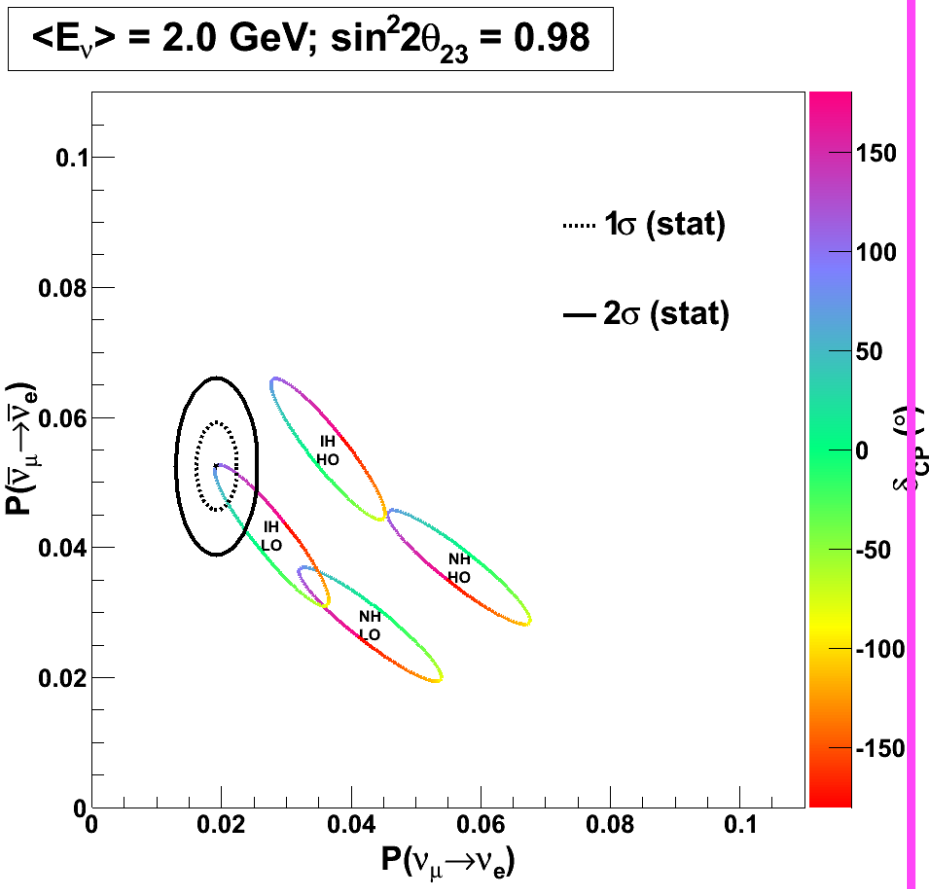


Oscillation probability depends on sign of Δm^2

How does it work? Experimentally



- After 3+3 years of ν and anti-ν running NOνA sees this
- θ_{23} uncertainty is now important : Fogli already prefers $\theta_{23}<45^{o}$
- MINOS and Super-K prefer non-maximal θ_{23}

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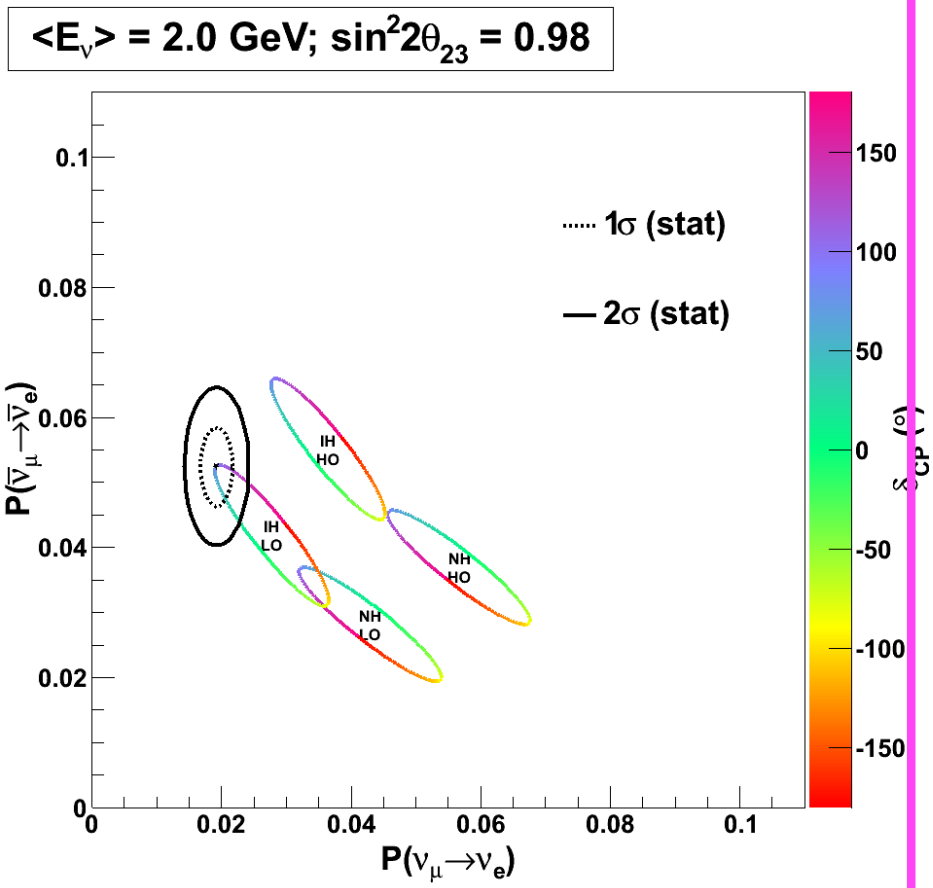

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- MINOS and Super-K prefer non-maximal θ_{23}
- Add 3+3 years of GLADE
- IF! its here you are lucky!

GLADE mass hierarchy reach

- Physics reach of GLADE alone similar to NOνA
- Combination with NOνA and T2K cannot be avoided
- Expectation is that $\sin^2 2\theta_{23}$ known to .01 by 2020 (now .04)
- θ_{23} in lower quadrant gives least sensitivity (shown)

LATEST T2K projection is 8.8e21 by 2021

Period	Integ. No. of Proton on Target	Beam Power (kW)	
-Jun.2012	3.1E+20	170	
-Jun.2013	7.8E+20	200	
-Jun.2014	1.2E+21	250	*2
-Jun.2015	1.8E+21	250	
-Jun.2016	2.5E+21	300	
-Jun.2017	3.2E+21	300	
-Jun.2018	3.9E+21	300	
-Jun.2019	5.5E+21	700	*1
-Jun.2020	7.1E+21	700	
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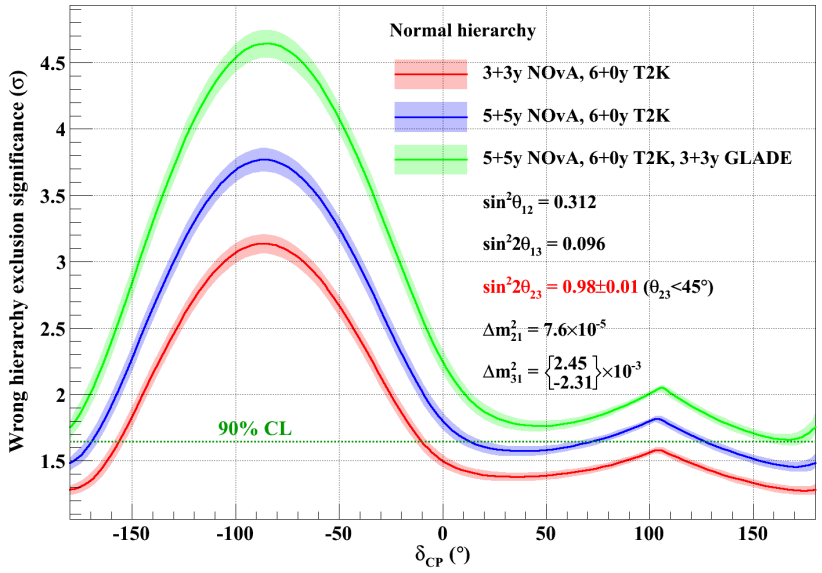
*1 Completion time of MR upgrade (assumed to be 2018) is suject to change, depending on economical situation, readiness and so on.

*2 LINAC upgrade completed

* Beam Energy 30GeV



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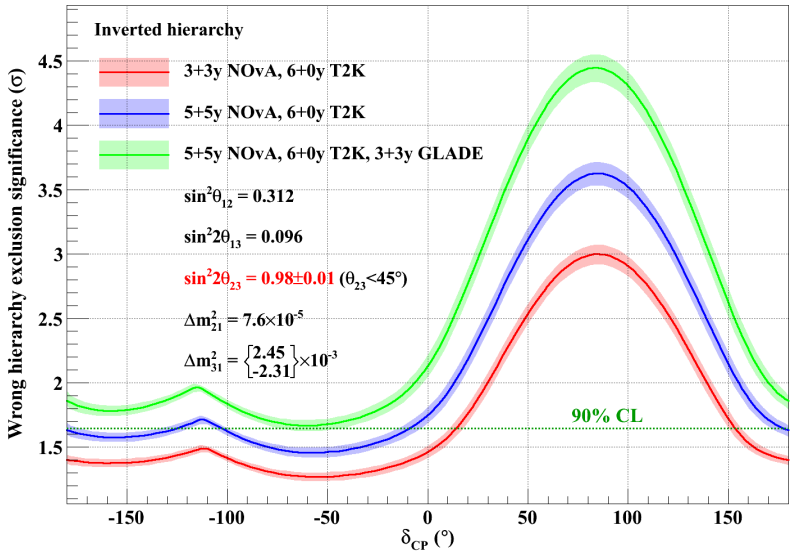

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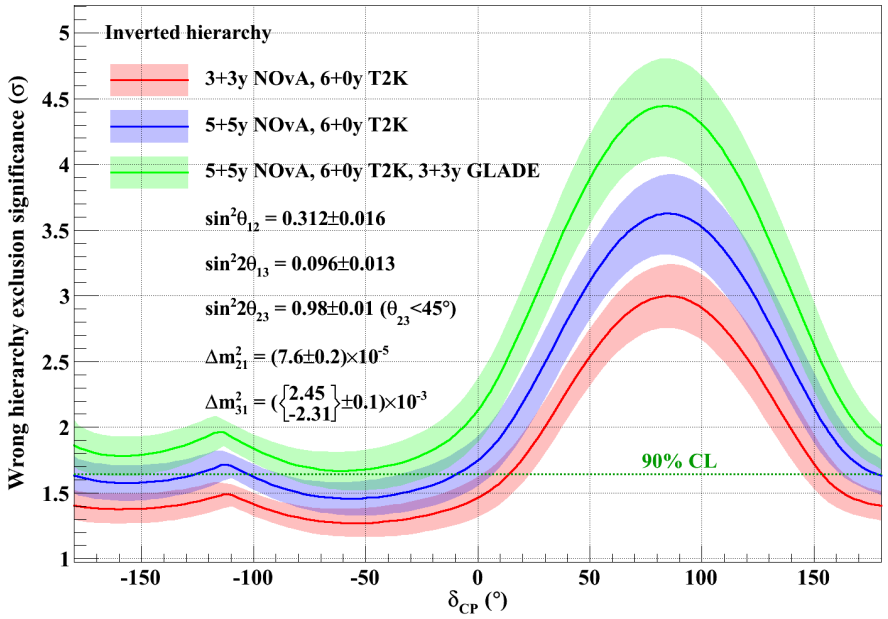

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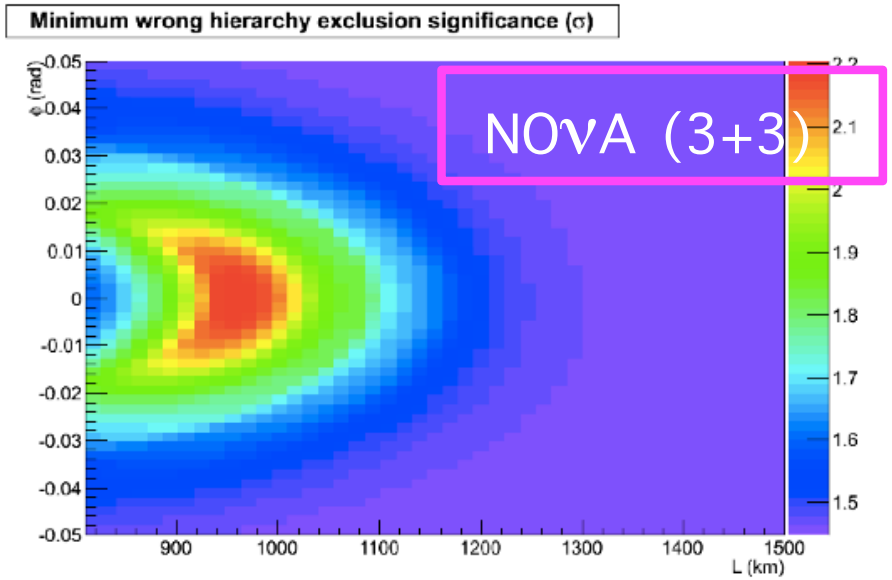

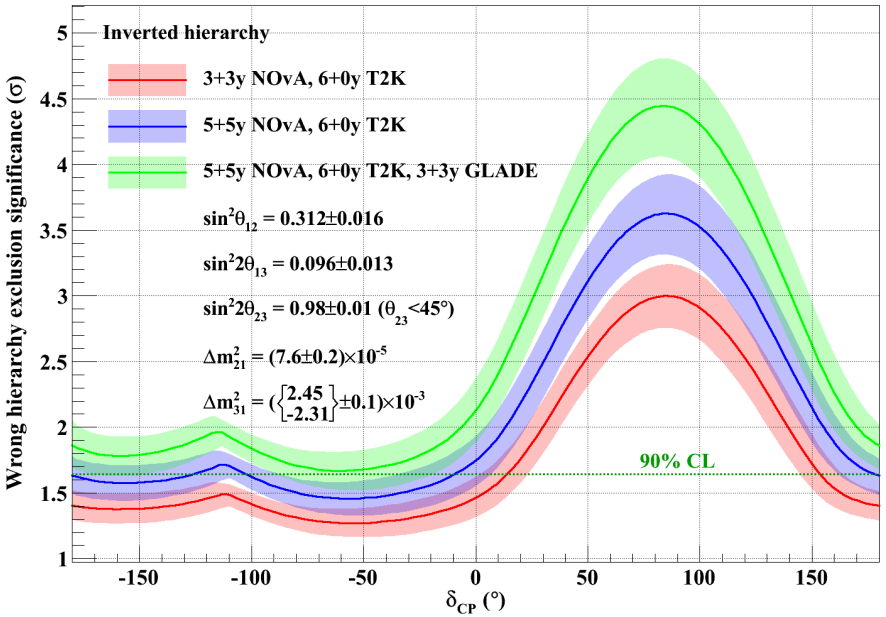

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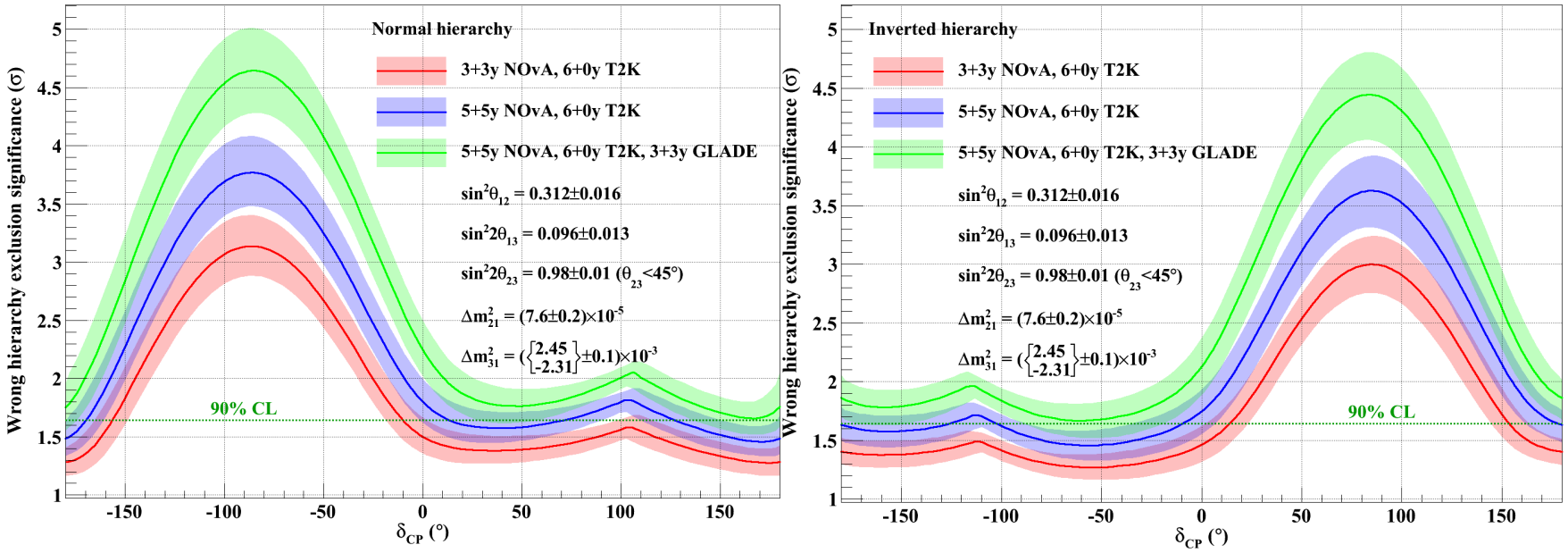
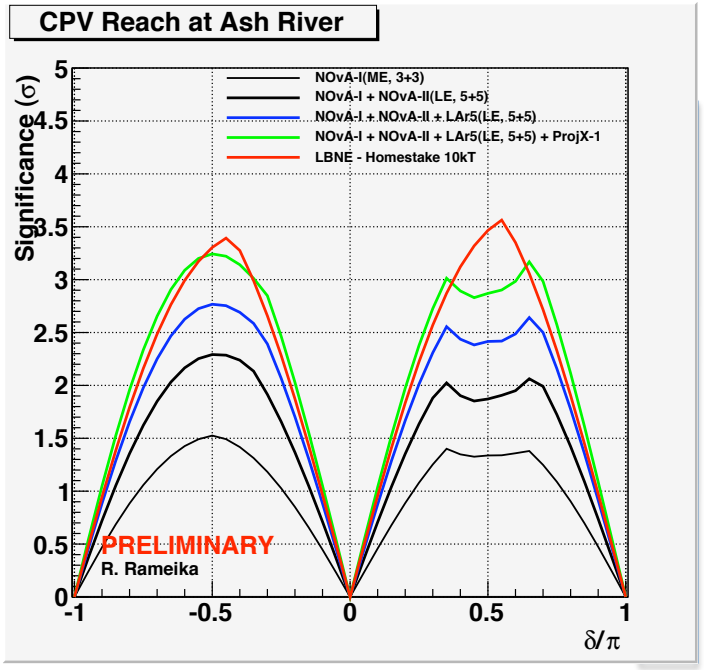
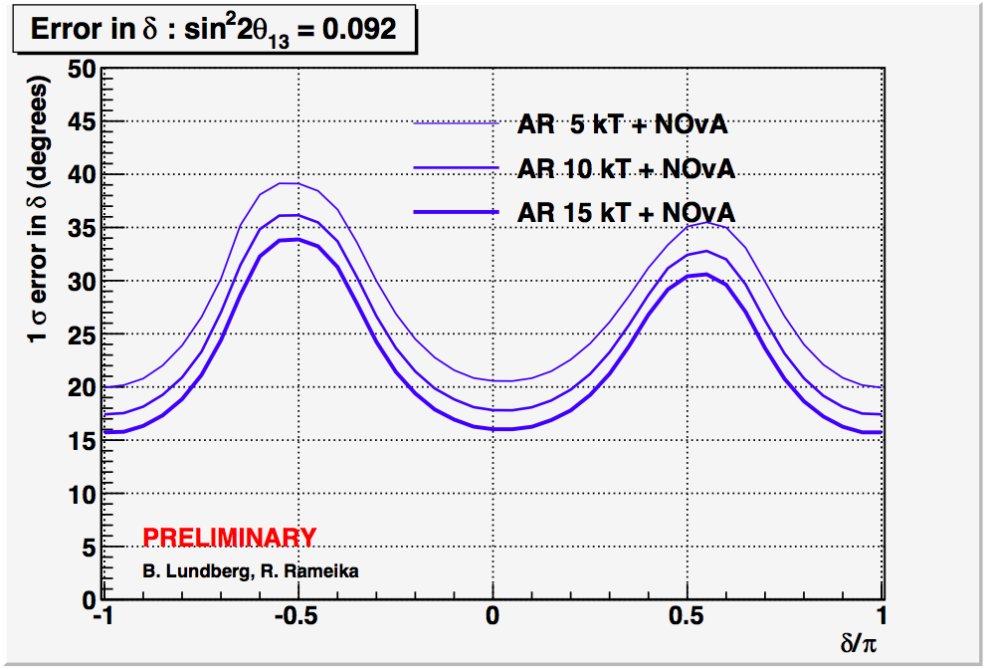


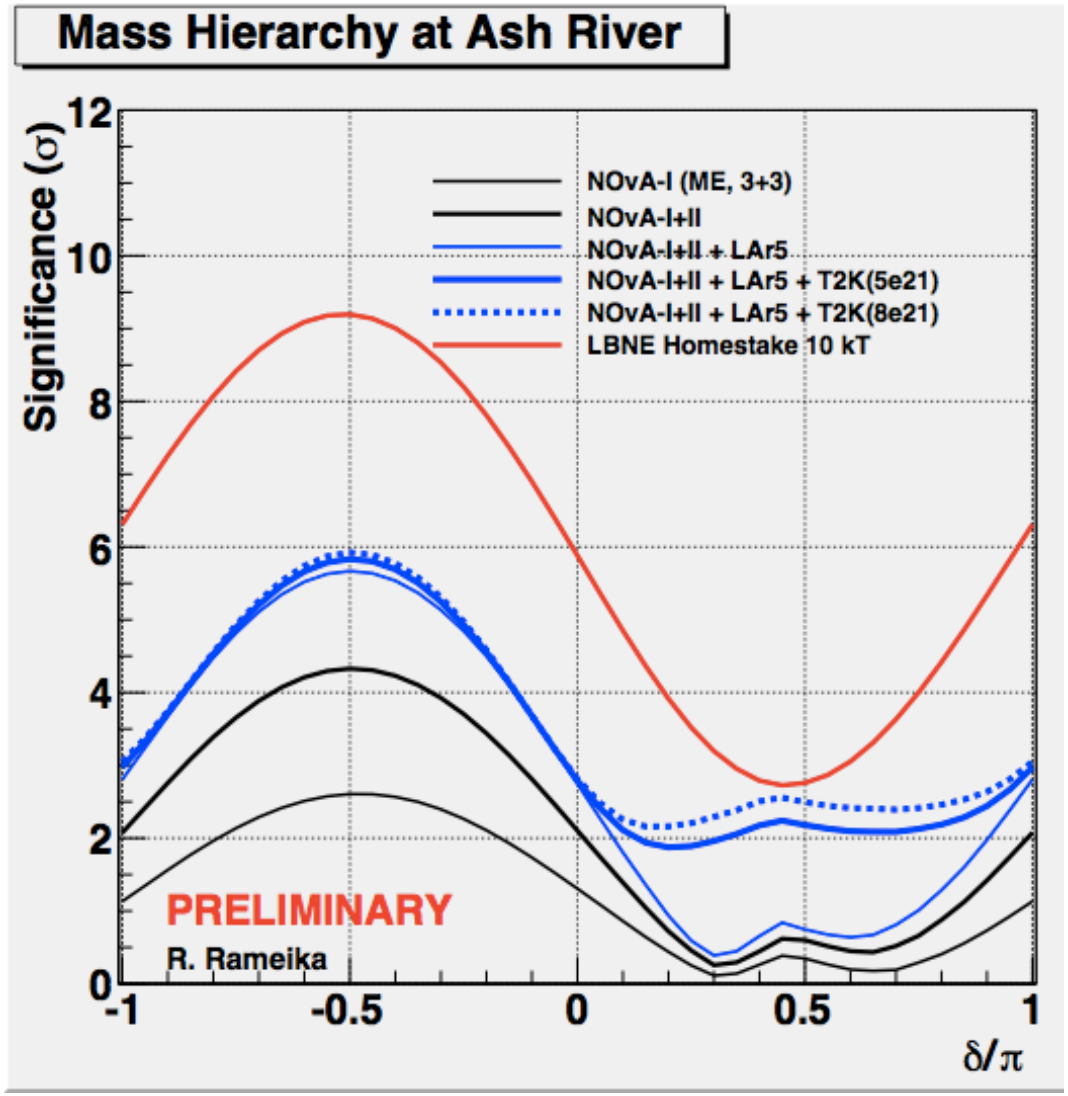
GLADE δ_{CP} reach

- Running now for 10 years total (2026)
- At Yanakida's prediction, ~2σ measurement
- Worst case δ_{CP} at between 35-45°
- Best case δ_{CP} at between 15-25°
- T2K will also have a 2σ? independent measurement



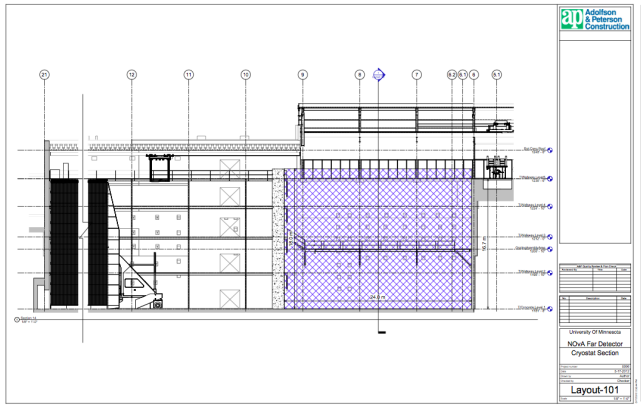


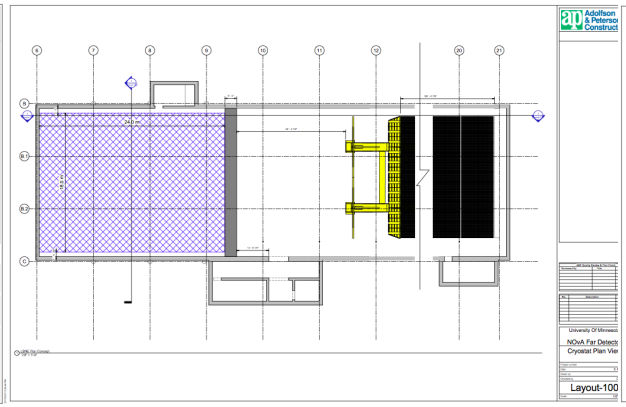
Long Term Backup

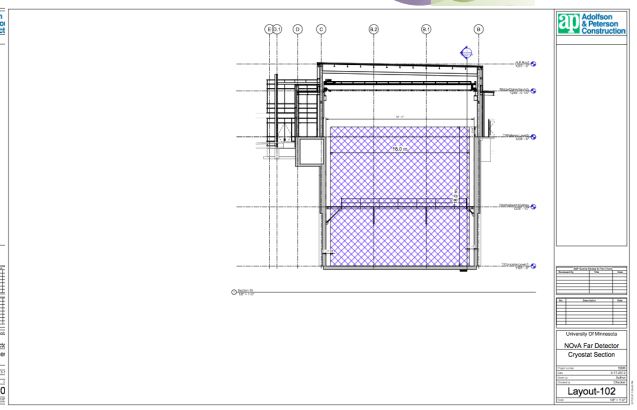


- 8+8 NOnA
- 5+5 GLADE
- 8e21 T2K
- Takes us to 2030.....

How can we do it?

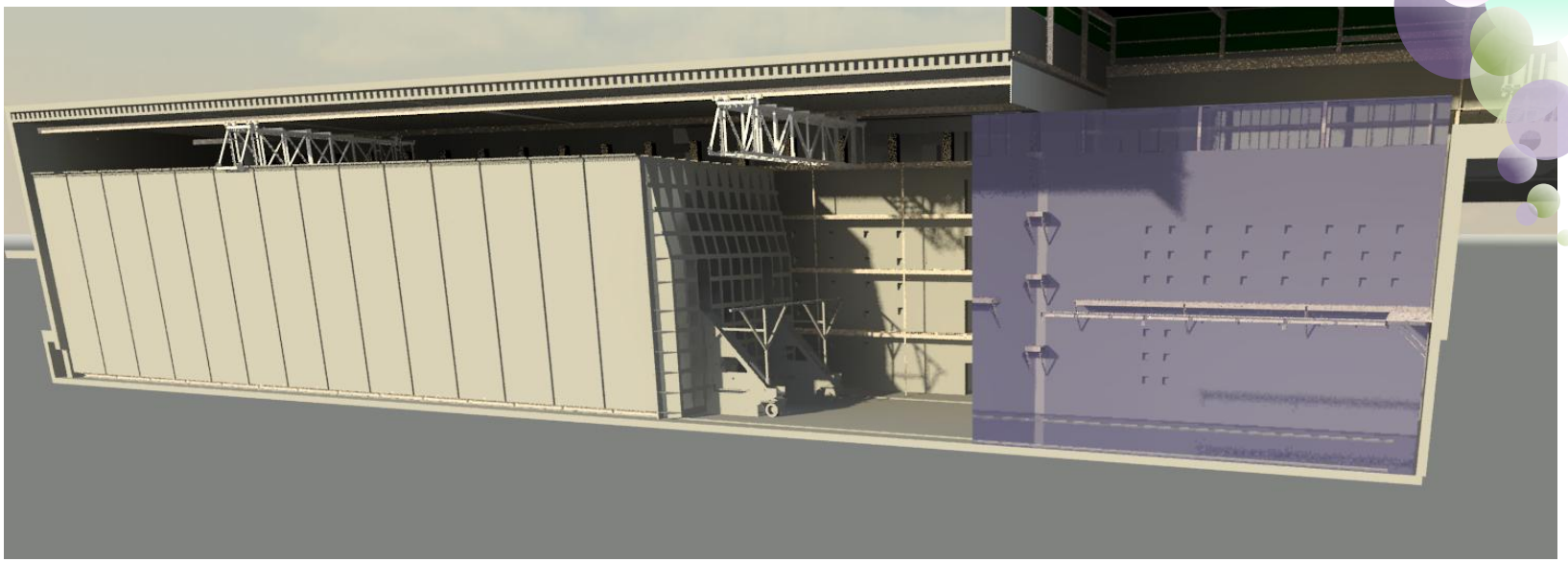






- Total volume available is 18m x 18m x 24m
- Will fit in at other end of Laboratory (pity its not at other end!)
- If dual phase used, height for drift distance will limit mass
  - 18m x 24m x 8m = ~5kT
- If "standard" wire readout used, maximum is closer to 10kT
- Space is ready: more power is needed

How can we do it?



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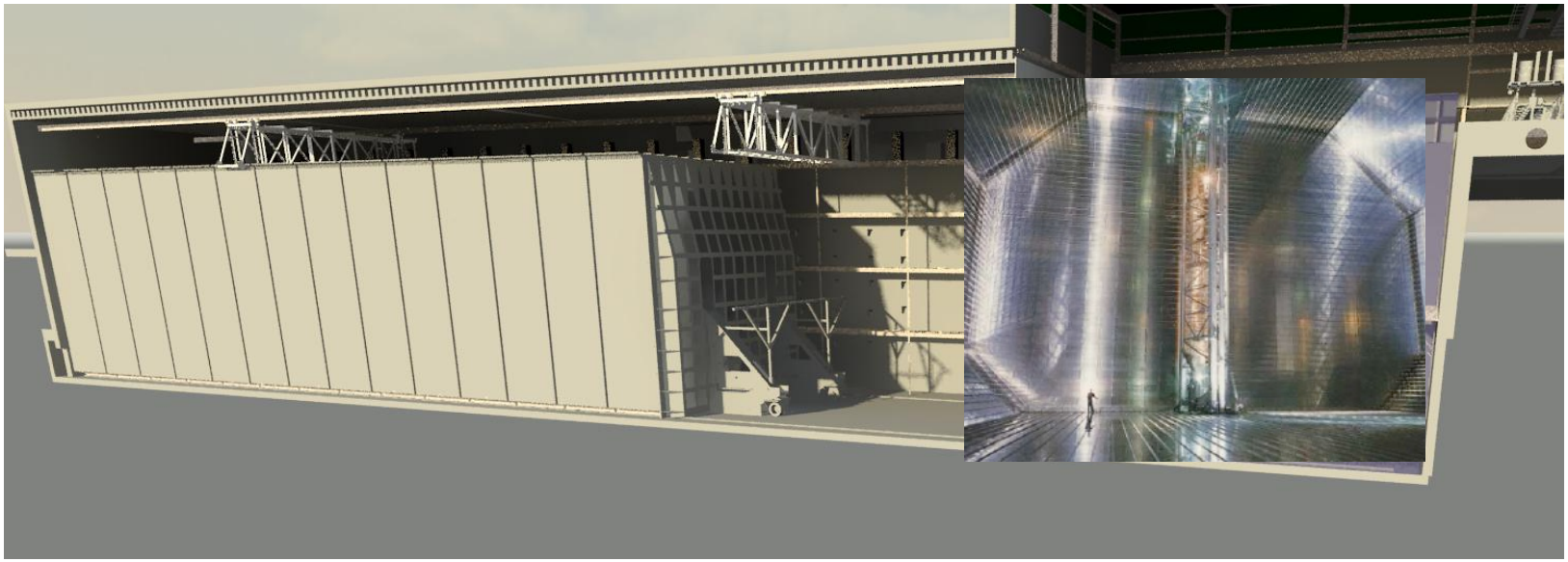
How can we do it? FAST?



- With help from University of Minnesota we can get started FAST
  - Build cryostat while achieving CD0 and completing R&D
  - Essential to persuading Europeans that this project will not be delayed
  - DoE University support will be needed for detector elements
    - These could be recycled into LBNE at the appropriate time
- European expertise will speed things significantly
- If PAC/Doe/FNAL make a CLEAR yes! statement, then we could start very soon

How can we do it? FAST?

- Getting university help is the only way to be competitive: DOE rules ensure delays are crippling for time competitiveness of large projects
- This at least when coupled to the real chance projects could get cancelled each year even after approval is major reason for European retiscence

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Website: www.physics.umn.edu

June 12, 2012

Professor Jenny Thomas
University College, London
Gower Street
London UK WC1E 6BT

Dear Jenny,

I met today with senior management of the University of Minnesota (Vice President for University Services Kathleen O'Brien, Vice President for Finance Richard Pfutzenreuter and Vice President for Research Timothy Mulcahy). The topic of the meeting was NOvA and possible post-NOvA neutrino experiments at the University's laboratories at Ash River and Soudan.

Topics at the meeting included the University's overall position with respect to post-NOvA Experiments and the ability of the University to manage both the work and the finances for a post-NOvA project. I informed the Vice Presidents that the scope of a post-NOvA project might range from somewhat less than $100 million to somewhat more than $800 million. With respect to cash flow financing, Vice President Mulcahy noted that the University of Wisconsin had advanced as much as $50 million for ICECUBE and that the University of Minnesota might need to consider cash flow management at a similar level.

I was instructed by the senior management to aggressively pursue post-NOvA projects. There are no commitments for funding. I would need to present specific proposals to this group before any definite cash flow commitments might be considered.

Please let me know if you have questions.

Best regards,

Marvin

Marvin L. Marshak
College of Science and Engineering Professor
Morse Alumni Professor

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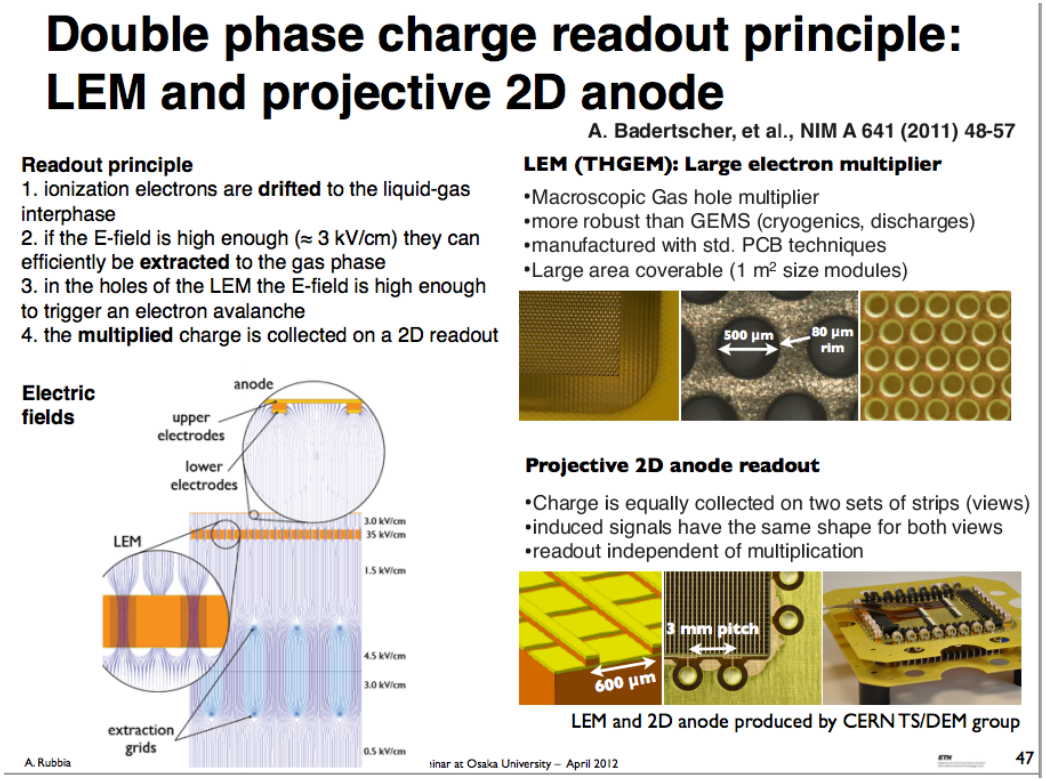
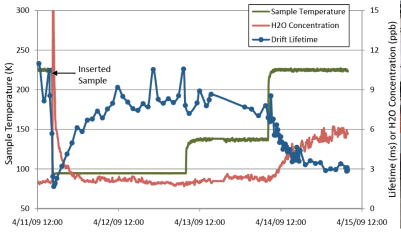
- Already demonstrated for MINOS and Ice Cube with NSF

Main Design Characteristics

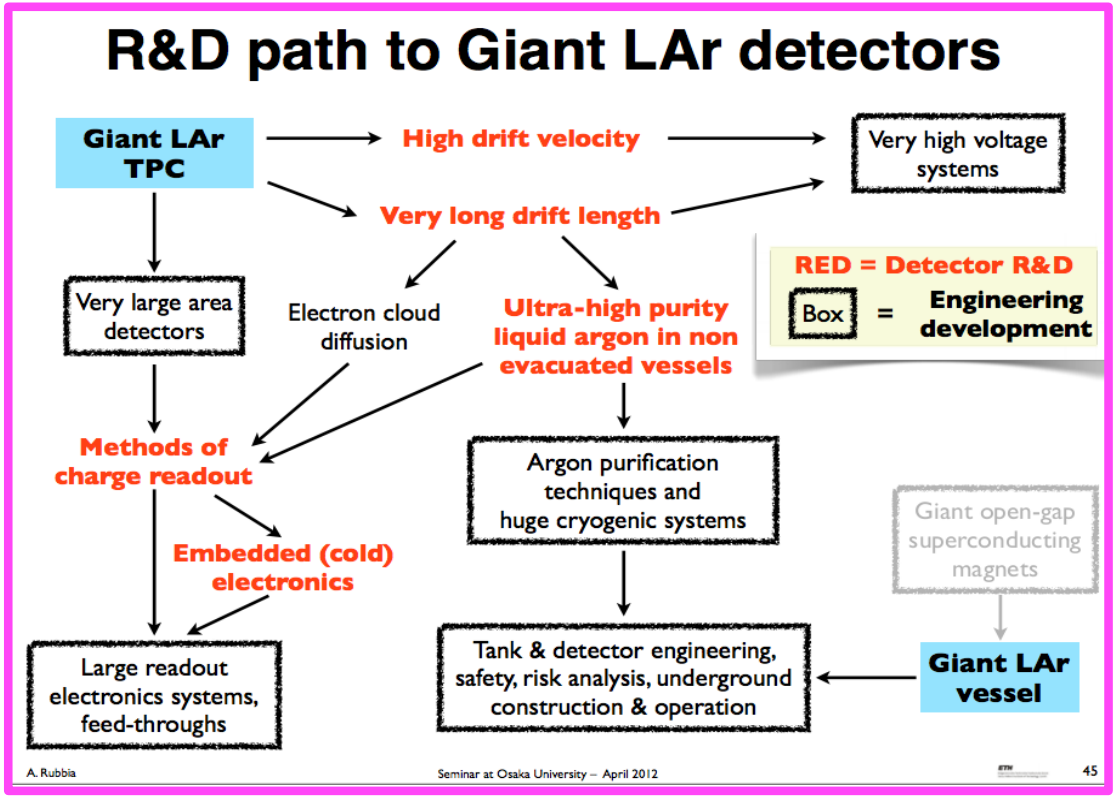
- For drift lengths > 7m, electron lifetime of 5-7ms
  - Depends on purity : demonstrated in Europe and US
- Total field of 1-2MV needed @ 0.5-1kV/m
  - Study done in Europe (arXiv:1009 4908) on Voltage multiplier
- Readout scheme could be dual phase or wires (maybe both?)
- Membrane technology understood and commercially available





R&D ongoing

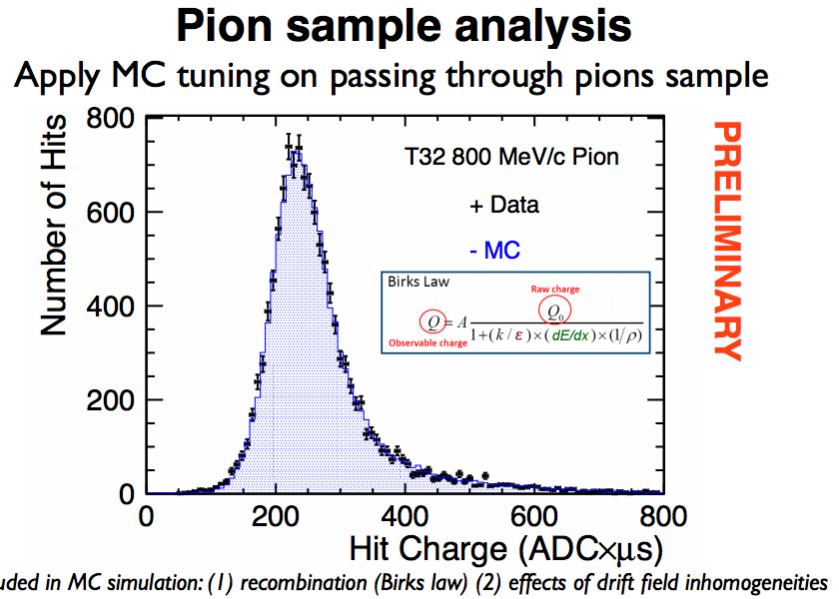
- Lots of interesting European/US overlap : this should be encouraged in BOTH directions!
- CERN will contribute infrastructure to help this R&D along
- Clear timeline will motivate all sides : European effort mostly would go through CERN



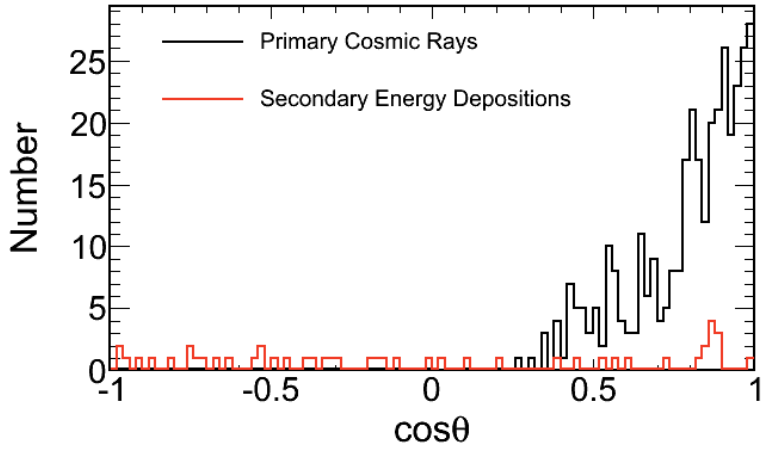
- US constructing microBooNE, gaining expertise but Europe (ETH in particular) still has the lead in technology and know-how

Reconstruction Effort

- This is starting to be globally organized
- Ongoing effort at FNAL shared amongst ArgoNeuT, microBooNE and LBNE
- New notable people signing up for effort
- MC simulation is being upgraded using existing data
- Cosmic simulations for microboone useful for GLADE background estimates



Included in MC simulation: (1) recombination (Birks law) (2) effects of drift field inhomogeneities



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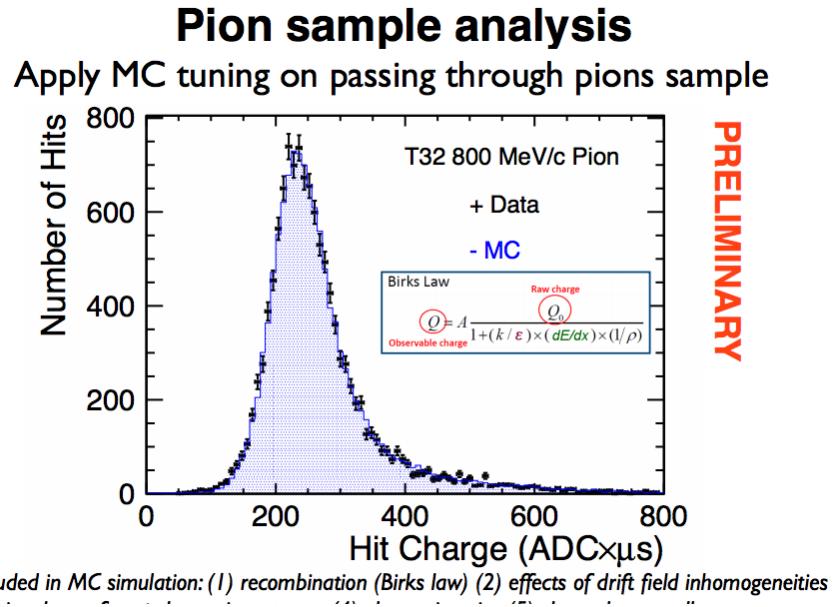

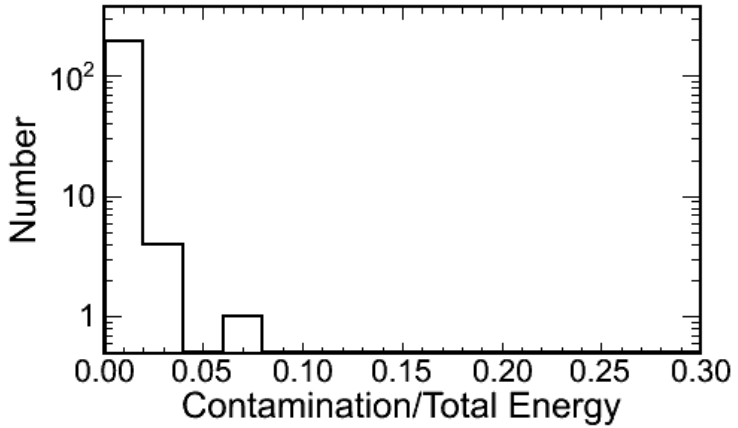

The collaboration

- First thing is to form a collaboration
  - FNAL, U.Minn, UK specifically, and other European and US groups in general have already expressed interest
- Possibility to have both a European and US readout design and share the LAr volume
- Presently collaboration between US and Europe on neutrino physics is rather pitiful
- If there is a concrete financial plan, the forming of the collaboration will be much easier
- Should ease further international collaboration in the future

Summary

- This is a great opportunity to build and run a very large LAr detector
  - Fund and push the short term R&D
  - Physics results for MH and CP in the next 5-10 years
  - Good Value : Infrastructure and beam already at Ash River
  - Opportunity (and necessity) to forge a real international (global) collaboration
    - Be ready for whichever opportunity comes next
    - Recycle detector elements to aid the Next Big Thing
- Will enable FNAL to be (even more) a part of the unfolding discovery over the next decade
  - Possibly even providing some insurance!